Optimizing Bone Defect Reconstruction—Balanced Cable Transport With Circular External Fixation

Stephen Matthew Quinnan, MD and Charles Lawrie, MD

Summary: Distraction osteogenesis has proven effective in the management of tibial bone loss from severe trauma and infection. Unfortunately, pain and scarring from wires and half pins dragging through the skin and the required prolonged time in the external fixator make treatment difficult. Cable bone transport has been shown to improve cosmesis and decrease pain during transport. However, the published methods have limitations in that they have poor control of transport segment alignment, do not allow for lengthening of the limb, and do not permit weight bearing during the treatment process. We describe a novel method of cable bone transport that addresses each of these limitations with excellent control of alignment including the transport segment, easy conversion to allow limb lengthening, and full weight bearing throughout the treatment process. In addition, the method facilitates multifocal transport and safe conversion to intramedullary nail fixation, both of which can be used to substantially shorten the time of reconstruction.

Key Words: bone defect, segmental defect, open fracture, tibia, cable transport, bone transport, distraction osteogenesis, external, ring, circular, bone loss, osteomyelitis, TATN

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INTRODUCTION

Management of segmental tibia bone loss associated with high-energy open fractures, osteomyelitis, and septic nonunion is a clinical challenge. Associated soft-tissue injury is often severe, and devitalization of large segments of bone is common leading to a high risk of deep infection.[1,2] Several strategies have been proposed to salvage these severely injured limbs, but distraction osteogenesis remains the most reliable method of creating high-quality new bone while minimizing infection risk.[3–8] Despite the historical success of distraction osteogenesis, the long duration of time in the fixator required for treatment (1.5–2 mo/cm) can be very onerous.[6,9–11] Soft-tissue complications including pin tract infection as well as discomfort and scarring from excursion of pins are persistent concerns. Soft-tissue injury can also be problematic when transporting into zones with flap or poor skin coverage and wires discourage joint range of motion and strengthening during reconstruction leading to the possibility of joint contracture.

Central cable bone transport (CBT), in which no pins or wires drag through the skin, has been proposed as an alternative to decrease pain and avoid scarring associated with skin tracts.[12,13] Results from 2 published methods of CBT showed improved pain control and cosmesis with union rates of 100% and no deep infections. However, there were limitations in weight bearing throughout treatment and no impact on time to successful union compared with traditional bone transport.

Combined methods with internal fixation and the use of multifocal osteotomies have been proposed to shorten the external fixator and reconstruction time.[14] Lengthening over a nail decreases external fixation time, but increased rates of infection have repeatedly raised concerns.[15–19] The risk of infection is attributed to difficulty in preventing external fixation components from contaminating the nail during transport and the risk associated with hardware contamination at the bone defect site.[20] Plating of the regenerate is similarly effective at decreasing fixator time but also raises concerns of infection and has been associated with plate breakage and varus malalignment in adults.[21–26] An alternative method is lengthening and then nailing (LATN). LATN is reported for limb lengthening in which only distal and proximal bone segments need to be considered. This is a key difference because having only 2 bone segments makes it relatively easy to avoid having wires and pins in the potential pathway of an intramedullary nail and eliminates the concern over a site with contamination and damaged soft tissues. Regardless, this technique had a very low infection rate and importantly a very definite reduction in healing time.[27]

The primary purpose of this study is to report the surgical technique of bone transport using central cables with circular fixation, "balanced cable transport with circular fixation," and its results in the treatment of 14 patients with large segmental tibia bone defects. This method can be performed almost entirely with fixator components that are widely available without expensive and rare custom parts and permits weight bearing as tolerated throughout the treatment process.

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The method provides highly accurate overall alignment and a reliably straight transport segment that can facilitate conversion to intramedullary nail fixation. We have termed the powerful combined technique of balanced cable transport with planned conversion to intramedullary fixation at completion of transport as "transport and then nailing" (TATN) in harmony with the previous report of LATN.

TECHNIQUE

Cable frame application is performed after adequate staged debridement and maturity of flap coverage when required. Surgical exposure is performed in the standard fashion along previous incision lines or as appropriate to raise overlying soft-tissue coverage. Typically, there is an antibiotic cement spacer in the defect from previous surgery that is removed and the bone ends are exposed. If not previously prepared, each bone end is resected to a point where at least 75% of the normal shaft surface area is present as a flat cut orthogonal to the axis of the shaft. This surface could include more than 1 fragment if fixed with lag screws and then cut, but all pieces must have identifiable punctate bleeding.

After bone end preparation, a long-braided stainless steel cable is applied to the transport segment. A transverse hole is made using a 4.8-mm drill at the midlevel of the intramedullary canal at least 1 cm proximal to the location at which the bone end is circumferentially intact. The cable is then passed from the medial hole across to exit out the lateral hole. The cable is then brought from the lateral side over the anterior cortex (this step helps because it is easier to grab the cable from the lateral hole then to pass it into the lateral hole). The trailing end is then brought out the medullary canal. The leading end of the cable is then placed back into the medial cortical hole and also brought out the medullary canal (Figs. 1A–E).

Preparing the cables for passing at the far bone end begins with using 2 heavy needle drivers to unwind the last centimeter or so of the cable (Figs. 1G–J). This is done to allow passage of a #2 nylon suture between the fibers of the cable. When released, the cable springs back and the nylon suture can pull perfectly in line with the tip of the cable. This is critical because the straight pull on the cable tip prevents it from getting hung up on the bone as it exits.

Next, a fulcrum for the cables is established in the opposite bone end (Fig. 2A). The fulcrum can be a half pin attached to the frame, a screw, or rarely a tensioned wire. Most commonly a 6-mm half pin attached to the frame is used as the fulcrum. The half pin is advantageous because it can be used even with a short segment and is secure in metaphyseal bone. Using a screw as the fulcrum is convenient because the frame can be brought on and off the leg without obstruction. The author has used both partially threaded 4.5-mm screws and intramedullary nail locking bolts as fulcrum screws. Originally, partially threaded screws were used because of a theoretical concern that screw threads could fray the cable, but experience has shown that the cables do not fray while sliding over screw threads. Locking bolts are now used exclusively when a fulcrum screw is used for TATN because the nail set is already needed at the time of frame removal. Despite their advantages, screws are used less than half pins because the author believes that they are not ideal in softer metaphyseal bone and prefers to have at least 1 cm of circumferentially intact cortex between the bone end and the screw. This may be overly conservative, and it may be safe to use fulcrum screws in metaphyseal bone or with less of a bone bridge, but we have no experience with these circumstances. High-tension Ilizarov wires are the most difficult to use as a fulcrum but provide an advantage for trifocal transport.

The location of the fulcrum should be in the center of the medullary canal on the anteroposterior view of the distal fragment and placed in the sagittal plane. Once the location is identified, an appropriately sized drill is passed and left in place. Following this, a transverse hole in the mid-medullary canal on the lateral view is drilled with a 4.8-mm drill a few millimeters distal to the fulcrum (Fig. 2B). The drill placed for the fulcrum helps identify the correct location for the more distally placed transverse drill path. The drill at the site of the fulcrum can then be removed for passage of the cables. A suture passer is then used to alternately shuttle a #2 nylon suture between the distal holes. This suture can be easily extracted from the intramedullary canal of the bone end. The nylon suture from the cable is placed within the nylon suture loop from the exiting hole, and the cable is advanced out of the far bone end. The cables are passed so that they exit the opposite cortex of the bone from which they entered at the other side of the defect (Figs. 2C–L).

Once the cables are passed, the fulcrum pin or screw is advanced through the existing drill hole. Either through direct visualization or fluoroscopy, it must be assured that the cables are passing distal to the fulcrum in opposite directions (Figs. 2M, N). Sometimes, both cables will want to stay on the same side of the fulcrum. If this happens, it is possible to either use a tonsil clamp within the medullary canal to push on the cable or, as a favored alternative, a Frazier tip suction passed through the 4.8-mm drill hole over the cable will allow for direct pressure on the cable at the desired location to keep it on the correct side of the fulcrum during passage. One important note is that if a half pin is being used as a fulcrum and the fulcrum is located in the distal bone segment, then it is important to pass the frame over the leg before placement of the fulcrum pin. If the frame is not sitting proximal on the leg at the time of pin placement, then it will be very difficult to advance the frame over the pin. Often, it is best to leave off the most distal ring of the frame until after pin placement is complete and then attach it. Before advancing the frame back into place, all wounds should be closed.

The circular fixator construct in all our cases consisted of spatial frame rings connected with threaded rods. If additional lengthening is needed after transport, then the proximal 2 rings are connected with telescopic rods. There should be at least 3 rings and if it is a trifocal transport with planned conversion to nailing, then there must be at least 4. We believe that most circular fixators can be used with this technique, but we chose spatial frame rings because fewer rings are needed for stability than with Ilizarov rings, facilitating access inside the frame. In addition, the option of adding struts for salvage of an error in alignment seemed valuable, although it was rarely necessary. Fixation is then applied in a standard fashion with stable proximal and distal fixation blocks.[28] If TATN is planned, then the proximal fixation block is configured as described for the LATN technique to assure a clear path for nail passage.[21] We consider most patients as candidates for TATN but would not recommend this when the proximal or distal segment is too small for locking screw fixation or if there is any indication that debridement has not completely eliminated infection. We recommend a minimum length of 32 mm of intact bone in the distal segment and 65 mm in the proximal segment to assure adequate fixation with TATN.

After fixation is complete, 2 pulley wheels are added to the frame to direct the cables toward the pulling motor (Figs. 3A–E). The cables are linked to a motor assembly using a slotted threaded rod or wire fixation bolt. We have successfully used 3 types of motors including telescopic rods, custom cable transport rods, and modified spatial frame struts. Telescopic rods are very reliable for pulling the cable, but they are tricky because they allow the cable to spin while advancing (Figs. 3H, I). The braided cables do not tolerate this and will fray and eventually rupture if this is allowed to persist. The solution to this problem is to build an antirotation rod (Fig. 3L). The rod is not directly attached to the cable or telescopic rod, but the post attached to the telescopic rod assembly slides over the threaded rod and prevents rotation allowing the telescopic rod to perform

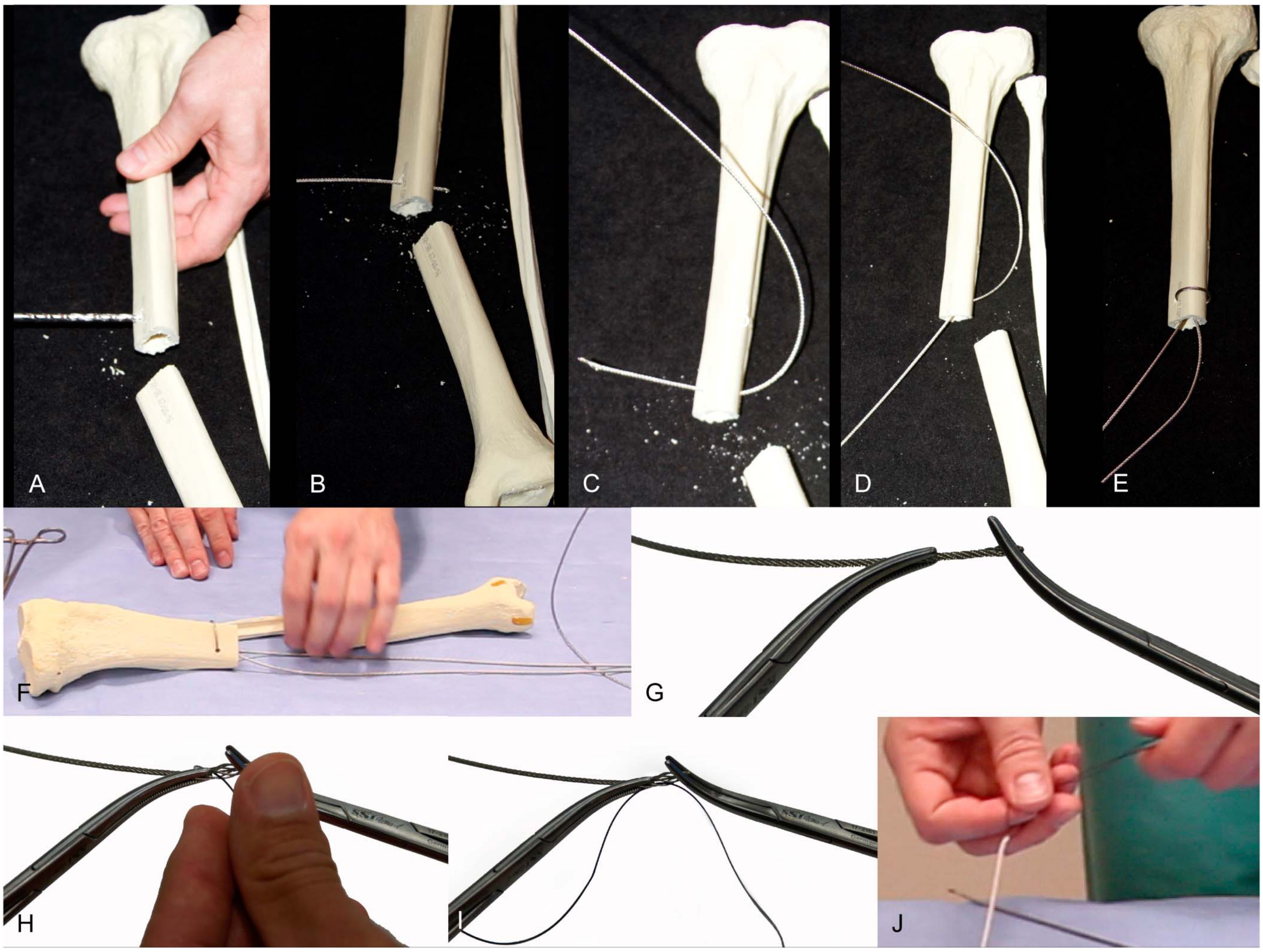

FIGURE 1. A, Transverse hole is drilled from medial to lateral in the middle of the medullary canal on the lateral view at least 1 cm above the end of the bone segment. B, Cable is passed from medial to lateral through the drill hole. C, Cable end is brought out from the lateral hole around the anterior cortex. D, Trailing end of the cable is brought out the intramedullary canal by using a clamp to pull it out. E and F, Leading edge of the cable is then again inserted through the hole in the lateral cortex and this time also taken out of the medullary canal. Both ends of the cable are now free in the bone defect. G, Cables are prepared for distal passage beginning with 2 heavy needle drivers used to unwind the braided cable until gaps can be seen between the bundles. H, A #2 nylon suture is passed between the bundles of the cable. I, Cable is released and springs back into position. J, It is now possible to pull directly on the end of the cable with the nylon suture.

a purely translational pull. Although antirotation rods successfully solve the issue of rotational fraying, their construction can be time consuming and adds complexity to the frame. For this reason, custom cable transport rods were manufactured that simplified frame construction and prevented rotation during pull (Fig. 3K). These worked well in a number of cases, but a manufacturing flaw in the locking ring caused a couple of them to fail and at present they are not available. Currently, we have moved to using spatial frame struts to pull the cable. To do this, the universal joint needs to be removed to allow attachment of the cable (Figs. 3F, G, J). Attaching 1 side of the strut to a ring facilitates universal hinge removal by increasing control of the strut, while wrenches are applied to the universal joint. Spatial frame struts are advantageous because the rod inherently does not rotate during translation, negating the need for an antirotation rod. It should be noted that each face of the strut is painted with a number from 1 to 4 to allow the patient to break up turning into 4 daily sessions and assure that the struts are turned in the correct direction (Fig. 3J).

Cables are locked into the slotted threaded rods after the motors are constructed and attached to the ring. The cables are placed within the slotted threaded rod with a nut above and below that will be used to lock the cable to the rod (Figs.

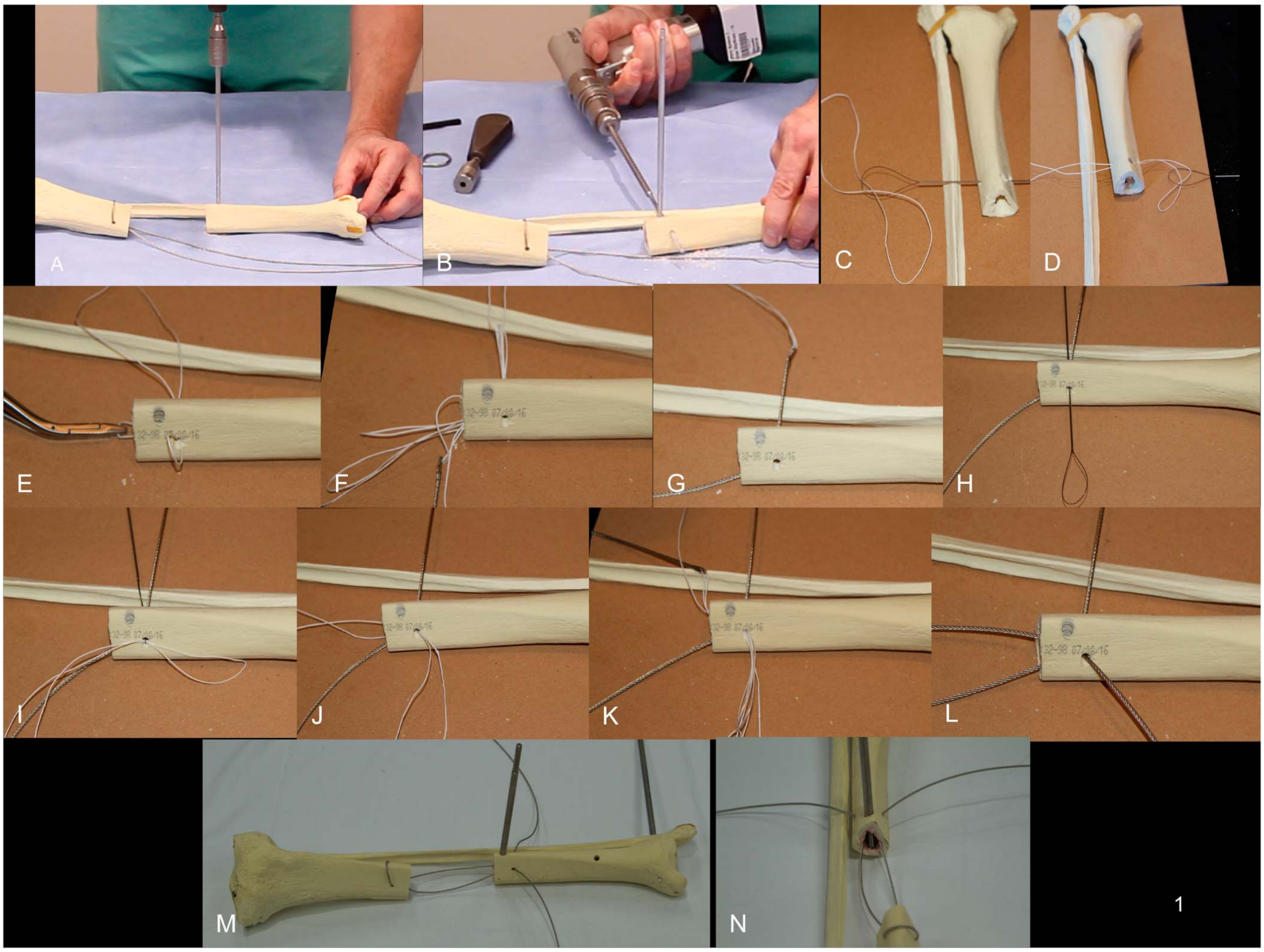

FIGURE 2. A, Drill or half pin is placed as a fulcrum in the sagittal plane in middle of the medullary canal on the anteroposterior view ideally 1 cm or more away from the bone end. B, Transverse drill hole is made from medial to lateral at least a few millimeters distal to the fulcrum across the middle of the medullary canal. C, Suture passer is used to grab a suture loop from the opposite side of the leg. D, Suture loop is pulled through the bone. E, Suture loop is extracted from the medullary canal into the bone defect. F, Suture attached to the cable is passed through the suture loop from the canal. G, Loop is pulled through the canal and out the cortex bringing the cable with it. H, Suture passer is passed in the opposite direction from the first passage. It will fit through the same hole as the cable if a 4.8-mm drill bit was used. I, Suture loop is pulled back through the bone with the suture passer. J, Suture loop is then brought out of the canal into the bone defect using a clamp. K, Sutures attached to the cable are passed through the suture loop and the loop is used to pull the cable through the bone distally. L, Both cables are now successfully passed through opposite cortical exit points. M and N, Fulcrum is advanced into the predrilled hole with care to assure that the cables cross on to exit the cortex on opposite sides from which they enter proximal.

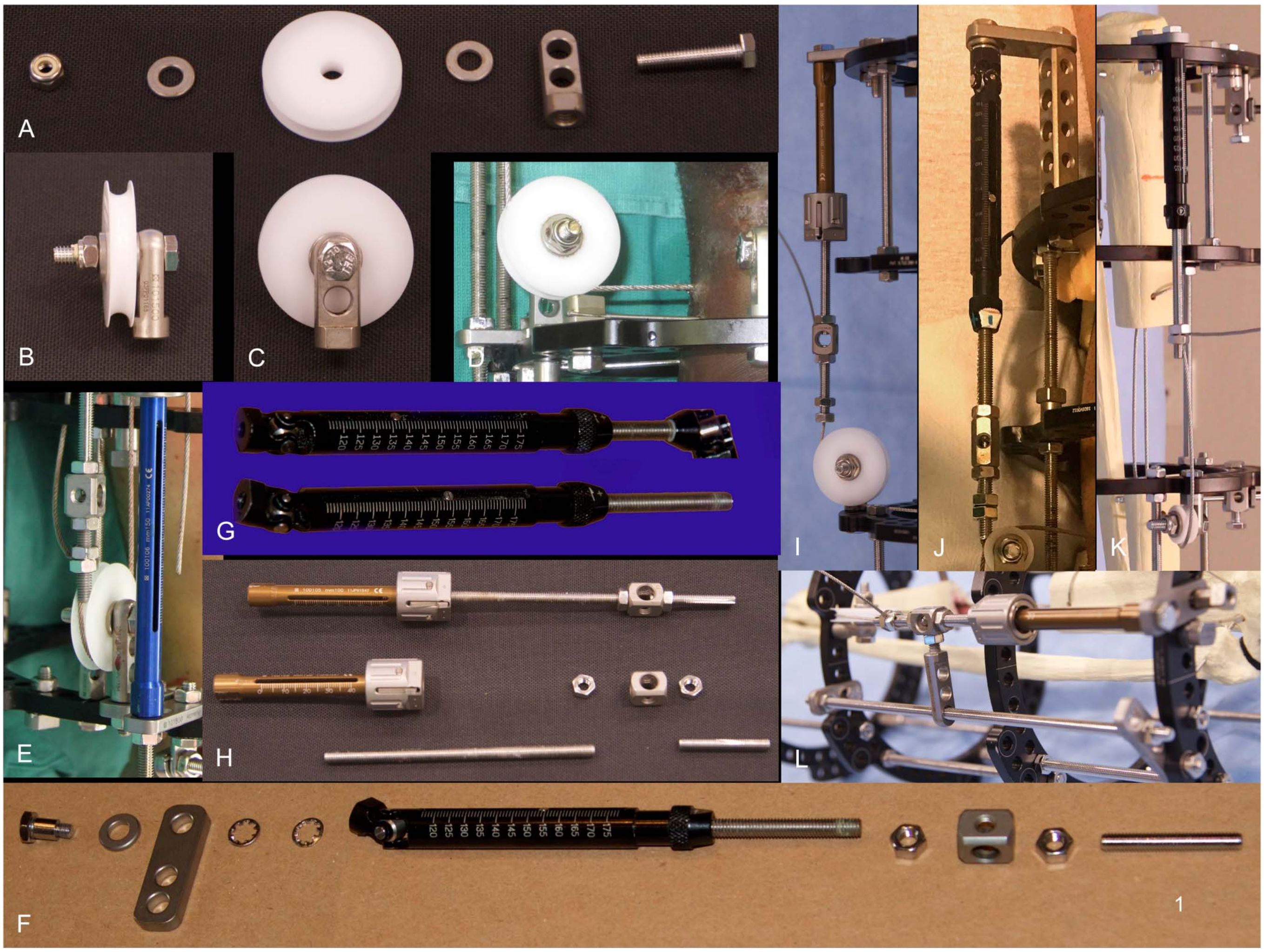

FIGURE 3. A, Assembly for cable pulley. B and C, Fully assembled cable pulley. D and E, Clinical example of cable pulley. F, Components for spatial frame strut cable attachment assembly. Components include shoulder bolt, 3-mm circular washer, extension plate (5-mm thick, can be any length), 2 star washers, spatial frame strut with shoulder bolt removed, 2 nuts, 1-hole Rancho cube or short socket, and a slotted threaded rod. G, Taylor spatial frame standard strut before and after removal of universal joint. H, Components for telescopic rod cable attachment assembly. Components include telescopic rod, threaded rod, 2 nuts, 1-hole Rancho cube, and a slotted threaded rod. I, Telescopic rod attached to cable through attachment assembly (note there is no antirotation rod attached in image, but 1 would be required). J, Spatial frame strut attached to cable through attachment assembly (no need for antirotation rod). K, Custom cable transport rod assembly. Setup includes a bolt attaching the base to the frame and 2 nuts locking the cable to the slotted rod (no need for antirotation rod). L, Telescopic rod assembly attached to antirotation rod. Note there is a post attached to the Rancho cube in the cable attachment assembly. The post slides over the parallel threaded rod without a direct attachment but will not allow for rotation of the Rancho cube. The threaded rod must be parallel to the telescopic rod.

3I–K). The cable is pulled tight with manual traction and then locked into position with the nuts.

The final step is to perform an osteotomy. The osteotomy is performed using a multiple drill hole technique through a small incision over the posteromedial corner of the bone. Osteotomies are made in the standard location in the metaphysis unless TATN is planned, in which case the osteotomy is usually made further from the joint toward the shaft. The osteotomy can be completed using an Ilizarov osteotome with a hexagonal handle together with a large wrench to rotate the osteotome within the osteotomy site. Alternatively, the author has found that an external fixator pin temporarily placed in the transport segment can be used to rotate the segment. This is a very easy way to both complete the osteotomy and confirm it is adequate. After the osteotomy is complete, the pin is removed.

Transport is begun after a latency period of 7 days at a rate of 1 mm/d divided into 4 turns daily each of 0.25 mm. This same rate is used at each osteotomy site if it is a multifocal transport with only internal cables pulling the bone. In this series, all patients returned to the operating room at the completion of bone transport for open docking with debridement of interposed scar tissue. Supplemental bone grafting at the docking site with iliac crest bone graft was used in 3 of the earliest cases. When bone graft was used, it was placed around the docking site after the bone ends were tightly apposed. No bone graft was used in the remainder of the cases, and bone graft is not routinely necessary in the author's experience. The author would only consider the use of iliac crest bone graft at the time of docking if 1 of the bone ends did not have a flat cut with 75% or greater surface area intact. In TATN procedures, we used an antibiotic cement–coated nail similar to that described by Conway.[29]

CLINICAL EXPERIENCE

After institutional review board approval, a retrospective review was performed at a single university level 1 trauma center. Orthopaedic trauma service case logs were used to identify all patients treated with CBT for the tibia between 2010 and 2017. Fourteen tibia bone defects in 14 patients treated by a single surgeon were identified. The average age was 39.4 years (19–83), and diagnoses associated with the segmental defects included severe open fractures 11/14, septic nonunion 1/14, and osteomyelitis 2/14. Other demographic data are presented in **Supplemental Digital Content 1** (see **Table**, http://links.lww.com/JOT/A129). The average total bone loss, which includes the length of the bone defect combined with the loss of limb length, was 11.1 cm. There were 5 patients with limb length discrepancy averaging 3.6 cm. Of the 14 patients, 4 were treated until healing in the cable transport frame until healed in frame (HIF), 2 were transported and then plated (TTP) to stabilize the regenerate after healing of the docking site, 1 underwent delayed nailing (DN) after healing of the ankle arthrodesis and a frame holiday, and 7 underwent TATN. Average follow-up time is 25.3 months (range 12–74).

Average external fixator time was 9.5 months, and external fixation index (EFI) was 1.02 mo/cm (Table 1). Average bone healing time was 13.0 months with a bone healing index (BHI) of 1.39 mo/cm. However, subgroup analysis showed very profound differences among the groups. External fixator time and EFI for the subgroups included 15.8 mo/1.84 when HIF, 9.0 mo/1.50 DN, 14.0 mo/1.47 with TTP, and 4.7 mo/0.36 with TATN. Bone healing time and BHI were 15.3 mo/1.80 with HIF, 12.0 mo/2.00 with DN, 27.5 mo/3.15 with TTP, and 9.1 mo/0.75 with TATN. Statistical analysis between the groups was performed using a Students *t*-test. EFI was shorter ($P \leq 0.0001$) with TATN compared with the HIF (0.36 vs. 1.85). EFI was also shorter ($P \leq 0.0001$) with TATN compared with TTP (0.36 vs. 1.50). BHI was shorter ($P = 0.000059$) with TATN compared with HIF (0.75 vs. 1.80) and shorter ($P = 0.006943$) with TATN than TTP (0.75 vs. 3.15).

Radiographic alignment (see **Table**, **Supplemental Digital Content 2**, http://links.lww.com/JOT/A130) revealed average joint angles of medial proximal tibial angle 87 (1),

TABLE 1. Surgical Details, Frame, and Healing Data

	Osteotomy								
Patient	**No**	**Site**	**Total Bone Loss, cm**	**Ex-Fix Time, d**	**Ex-Fix Time, mo**	**EFI, mo/cm**	**Healing Time, mo**	**BHI, mo/cm**	**Follow-up,mo**
Treated to completion in frame									
1	1	P	12.7	646	21.0	1.7	19.0	1.5	74.0
2	1	P	7.0	455	14.0	2.0	14.0	2.0	20.0
4	2	P and D	6.1	344	11.0	1.8	11.0	1.8	40.0
5	1	D	9.0	543	17.0	1.9	17.0	1.9	45.0
Average			8.7	497	15.8	1.84	15.3	1.80	44.8
Converted to nail after docking site healing									
3	2	P and S	6.0	299	9.0	1.5	12.0	2.0	54.0
Average			6.0	299	9.0	1.50	12.0	2.00	54.0
Converted to plate after docking site healing									
6	1	P	7.7	409	13.0	1.7	37.0	4.8	29.0
8	1	D	12.0	466	15.0	1.3	18.0	1.5	32.0
Average			9.9	438	14.0	1.47	27.5	3.15	30.5
Planned immediate conversion to IMN after transport									
7	2	P and D	14.2	126	4.0	0.3	7.0	0.49	17.0
9	2	P and D	20.8	263	8.0	0.4	13.0	0.63	43.0
10	1	P	15.4	126	4.0	0.3	11.0	0.71	22.0
11	1	P	6.7	90	2.0	0.3	7.0	1.04	15.0
12	1	P	15.4	186	6.0	0.4	8.0	0.52	14.0
13	1	P	6.5	134	4.0	0.6	8.0	1.23	12.0
14	1	P	16.2	181	5.0	0.3	10.0	0.62	14.0
Average			13.6	158	4.7	0.36	9.1	0.75	19.6
Total combined									
Average			11.1	305	9.5	1.02	13.0	1.39	25.3

D, distal; IMN, intramedullary nailing; No, number of osteotomies; P, proximal; S, shaft of bone on the same side of the bone defect as second osteotomy.

medial distal tibial angle 89 (1), posterior proximal tibial angle 79 (1), and anterior distal tibial angle 81 (2), rotation 0 (0).[30] Subgroup analysis revealed that alignment was uniformly excellent and generally within 2 degrees of the normal average in all regards except for the patients treated with plating of the regenerate, in which there were 2 measures >5 degrees (posterior proximal tibial angle 73, anterior distal tibial angle 86) but no deformities in any patient >7 degrees. There was 1 patient who had a 4-cm leg length discrepancy after healing, and all others had equal leg lengths. The patient with a discrepancy was intentionally left short to allow more rapid healing of the tibia to facilitate care of a severe ipsilateral open distal femur fracture and was later corrected with an internal lengthening nail.

The 1 major complication was an anterior tibial artery laceration that was successfully repaired (see **Table, Supplemental Digital Content 3**, http://links.lww.com/JOT/A131). The complication occurred at the time of the osteotomy in the second patient in the series. Although arterial laceration is a known risk of osteotomy, the complication likely could have been prevented, had we previously developed the methods of completing the osteotomy described above. In addition, 8 patients encountered obstacles during reconstruction that resulted in return to the operating room for a total of 11 unplanned procedures. All the obstacles are inherent to the use of external fixation for bone transport and not particular to our technique. Each obstacle was successfully addressed during treatment and resulted in no long-term sequelae. The total number of procedures from time of injury to complete reconstruction was an average of 11.1 per patient. Procedures during the reconstruction averaged 4.5 per patient but varied among the subgroups. Examples of planned procedures during reconstruction include application of the frame, osteotomy, removal, and/or

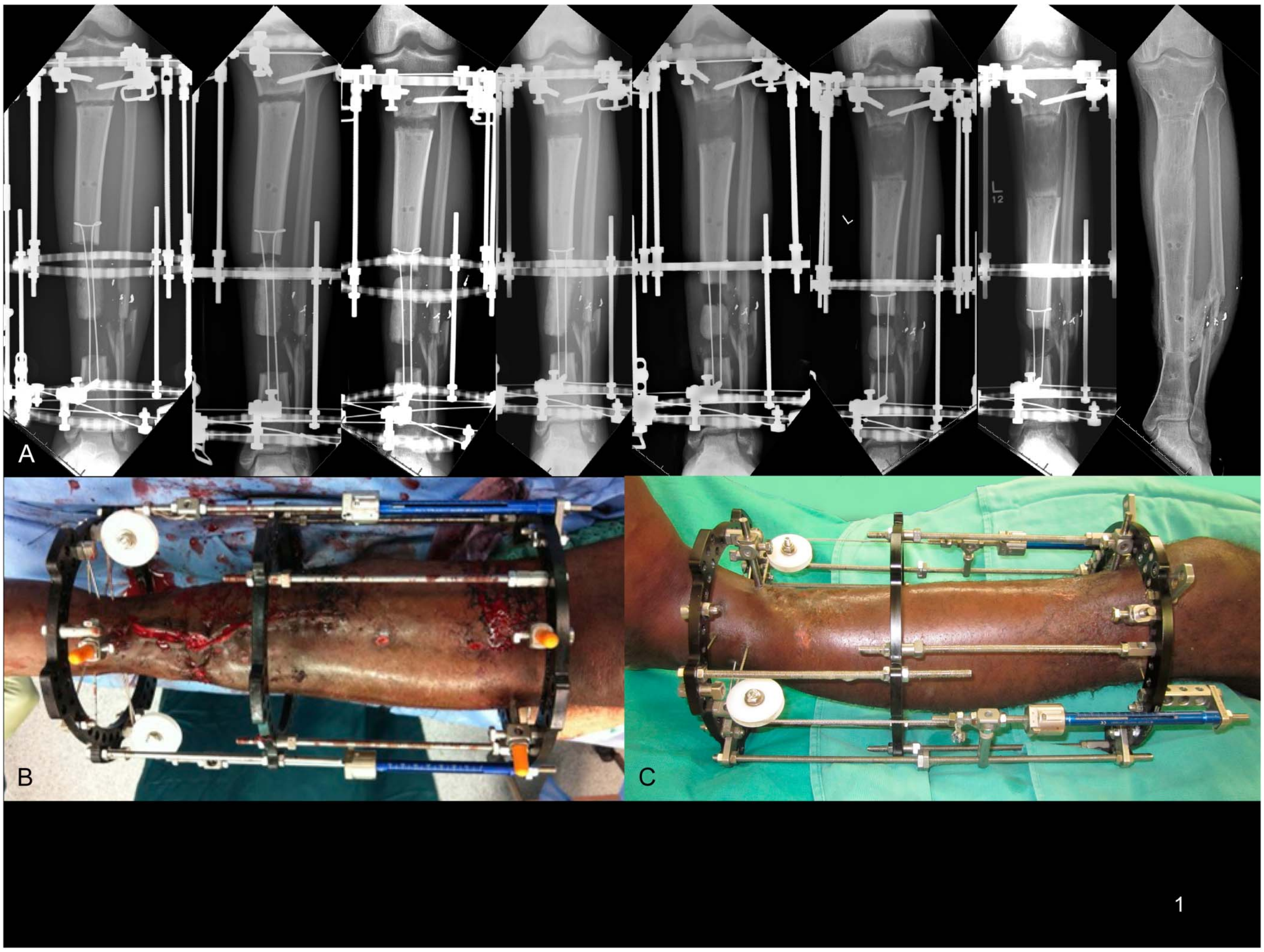

FIGURE 4. A, A 35-year-old man with a 12.7-cm defect from a high-velocity gunshot wound treated to healing in cable transport circular fixator. Radiographic series shows balanced pull of the 2 sides of the cable aims the distal end straight to the fulcrum and eliminates waggle in the transported segment. Note the progressive straightening of the transport segment and trailing regenerate column throughout transport. B, Clinical photograph of cable transport frame and leg before transport. C, Clinical photograph of cable transport frame and leg at time of healing.

exchange of cannulated cement spacer, open docking, fibular osteotomy for additional lengthening, revision of frame to prepare for staged internal fixation (earlier cases before TATN and 2 of the trifocal transports), staged internal fixation, and removal of the external fixator.

DISCUSSION

Although we did not include pain and cosmesis outcome measures, observation showed improvement in both and there were no problems beneath rotational and free flaps. Patients treated in the cable external fixator until healing had EFI and BHI of 1.80 mo/cm, which is commensurate with other methods of distraction osteogenesis.[4,31] Overall, alignment was improved with the use of circular fixation in our series compared with others using monolateral external fixation. Transport segment control is also improved by having a balanced pull on each side of the segment from the 2 ends of the cable instead of having a single attachment point that allows the proximal end of the segment to waggle (Fig. 4). In fact, our alignment data show an average variation from normal anatomic of only 1 degree.

Planning for conversion of the transport frame for lengthening is simple and requires only a change in the position of attachment of the cable. This is a clear distinction from other CBT methods that do not accommodate lengthening after transport. In addition, all patients in this study were allowed immediate full weight bearing in the external fixator. By contrast, Baumgart reported an average of 466 days (47 d/cm) to full weight bearing, whereas Kucukkaya transitioned during the consolidation phase.[12,13]

Although the above differences make our method an attractive alternative, we believe that the greatest advantages are facilitation of multifocal transport and combination of this method with TATN. The absence of wires and half pins in the transport segment unique to CBT greatly facilitates this conversion. In addition, as opposed to methods that use monolateral fixation, circular fixation allows the wires and half pins in the proximal fixation block to be positioned remote from an intramedullary nail path. Alternatively, there is an option to remove some wires from the path of the nail in clinic well in advance of conversion. Data from the combined method with TATN showed remarkable success. The EFI was 12.4 d/cm, which is equivalent to the best alternative methods with combined internal fixation. The BHI was exceptionally fast at 0.75 mo/cm. Trifocal transports with TATN were even more efficient with EFI 8.8 d/cm and BHI 0.49 mo/cm seen in 1 patient treated for a 14.2-cm defect. In all cases, regenerate healing was the rate-limiting step and docking site healing was rapid.

It should be recognized that these injuries remain very complex and labor intensive to treat. There was an average of 11.0 procedures from day of injury through final follow-up. The skeletal reconstruction stage required 4.6 procedures per patient. The number of true complications was low, but there were a significant number of obstacles causing return to the operating room for unplanned procedures. Despite these considerations, we believe that balanced cable transport with circular fixation provides an exciting new treatment alternative that optimizes the use of distraction osteogenesis in the treatment of tibia bone defects.

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